

Uncertainty of Propagation and Reverberation in Shallow Water Environments due to Seafloor Variability

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Document Number: N00014xxxxxxxxxxxxx
<http://www.nrl.navy.mil>

LONG-TERM GOALS

To work closely with the other members of the Seafloor Variability Team to map measures of the variability of the morphological, geoacoustic, and scattering properties of the seafloor into measures of the resulting variability of acoustic time series and reverberation in bottom interacting shallow water environments.

OBJECTIVES

Evaluate the relative importance of various types of seafloor variability on the predictability of the temporal evolution of acoustic transmissions and reverberation in shallow water waveguides. The measures of uncertainty include the predictability of the levels of the transmissions/reverberation, the decay rates, and the coherent features of the time-depth evolution of the receptions. Seafloor variability measures include 1) the uncertainty in the background sound speed, density and attenuation of the seafloor sediments, 2) the spatial variability of these properties about the background levels, 3) the variability in the bottom bathymetry, and 4) variability in the bottom scattering strengths which cause bottom reverberation.

APPROACH

Develop statistical models for the coherent properties of shallow water propagation and reverberation in the presence of environmental variability. The models are based upon adiabatic normal mode estimates of the Green function and either perturbational or Lambert's law type scattering functions. Adiabatic normal mode Green functions exhibit sensitivity to environmental variability in the group speeds and the phase evolution of the modes. Their use allows the development of closed form expressions for waveform decorrelation and for the variability of the expected value of the coherent signal field caused by bottom variability [1]. Using adiabatic normal modes it is convenient to represent the bottom variability with Empirical Orthogonal Functions (EOFs.) In this way closed form solution for the moments of acoustic propagation and reverberation time series is tractable if 1) the bottom EOFs are assumed to affect the phase and group speeds of the modes in a perturbative linear way, and 2) if the EOFs are assumed to be independent of one another. This latter assumption is most appropriate for homogeneous bottom variability processes.

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 30 SEP 2002		2. REPORT TYPE		3. DATES COVERED 00-00-2002 to 00-00-2002	
4. TITLE AND SUBTITLE Uncertainty of Propagation and Reverberation in Shallow Water Environments due to Seafloor Variability				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory,,4555 Overlook Ave SW,,Washington,,DC, 20375				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT To work closely with the other members of the Seafloor Variability Team to map measures of the variability of the morphological, geoacoustic, and scattering properties of the seafloor into measures of the resulting variability of acoustic time series and reverberation in bottom interacting shallow water environments.					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 7	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

The measures of the bottom uncertainty are provided by the other members of the Seafloor Variability team. The seafloor depositional processes are modeled by James Syvitsky (INSTARR) and Lincoln Pratson (Duke,) both of whom have the capacity to map modeled bottom depositional properties into equivalent geoacoustic properties from which variability metrics can be derived. In tandem, the experimentalists (Charles Holland (PSU,) John Goff (UTIG,) and Larry Mayer (UNH)) characterize the morphological, geoacoustic, and scattering properties of real sediments, giving ground truth estimates of the bottom variability metrics. These team members also quantify uncertainty introduced by measurement errors.

We work with team members to generate statistical EOF type characterizations of the modeled and measured geoacoustic and morphological variability of the bottom. These characterizations are then used in the statistical acoustic models to determine the sensitivity of the acoustic propagation and reverberation to the various seafloor variability metrics.

WORK COMPLETED

This year the results previously obtained for the predictability of shallow water time series due to oceanographic variability [2] were applied to the bottom variability problem. In addition, the time series variability Green function used in [2] was applied as the Green function inside a previously developed coherent reverberation model [3], giving consistent representations for modeling the sensitivity of propagation and reverberation time series to oceanographic or seafloor variability.

RESULTS

We have calculated the sensitivity of the time-depth history of acoustic arrival time series in shallow water to oceanographic variability (internal waves of level 1 Garrett-Munk,) and two types of bottom variability: 1) sound speed defects of ± 20 m/s in a slow sediment with a background sound speed of 1482 m/s, and 2) attenuation defects of ± 0.018 dB/• in the same sediment, which has a background attenuation of 0.06 dB/•. A realization of the oceanographic variability is shown in Fig. 1 and that of the bottom variability is shown in Fig. 2. The impact of oceanographic variability on 500 Hz shallow water acoustic time series is illustrated in Fig. 3. The top panel shows the time-depth history of the acoustic intensity received at 10 km in the absence of oceanographic variability, the middle panel shows the expected value of the acoustic intensity in the presence of oceanographic variability, and the bottom panel shows the standard deviation of the acoustic intensity normalized by the expected value from the middle panel. The results show that it is the earliest part of the time series, conforming to near axial propagation, which is most sensitive to internal waves in shallow water environments. This is because the correlation length scales of the sound speed perturbations caused by the internal waves are highly anisotropic, with very short vertical correlation length scales, and very long horizontal length scales. Axial propagation therefore accumulates more uncertainty by propagating along the direction of the longer correlation scale of the perturbations, while the later arriving surface-bottom multiples accumulate less uncertainty as they travel more nearly along the axis of the shorter correlation length scale.

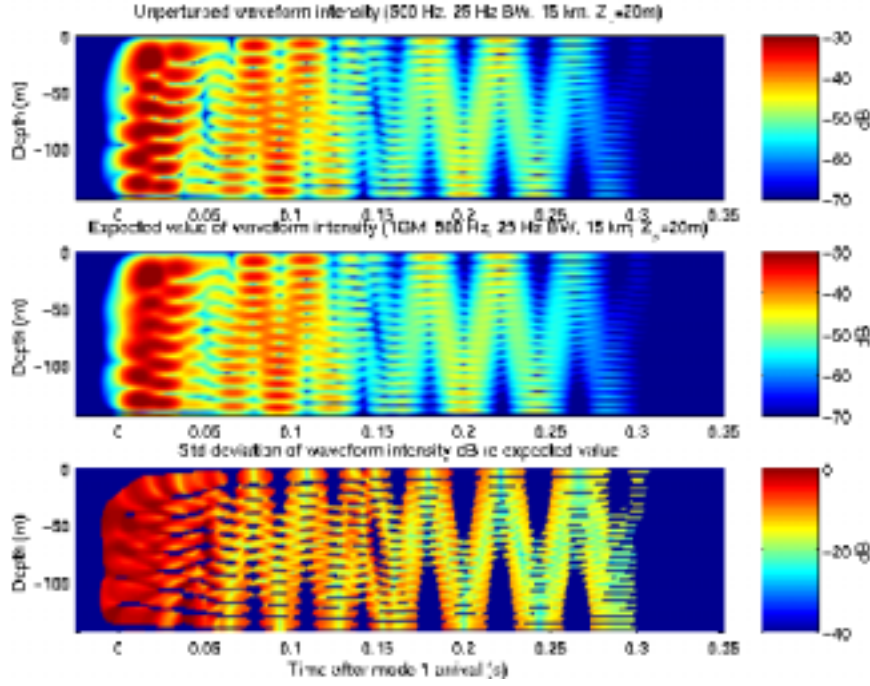


Figure 3. Unperturbed (top), mean (middle) and normalized standard deviation (bottom) of the time-depth evolution of received intensity in a shallow water waveguide in the presence of internal waves. The middle and bottom panels show that the initial part of the arrival is the most sensitive to the internal waves, with a correspondingly lower expected value and higher standard deviation.

In Fig. 4 the uncertainty of the acoustic time series due to variability of the sediment sound speed is shown. As before the top panel shows the unperturbed time-depth intensity arrival structure, while the middle and lower panel show the expected value of the intensity and the normalized standard deviation for sound speed defects of ± 20 m/s. In comparison to the oceanographic variability results, one sees that the entire time series is highly sensitive to the bottom sound speed variability, with resulting lower predictability of the coherent time-depth arrival structure and higher standard deviations over the entire structure.

Finally in Fig. 5 we illustrate the sensitivity of the arrival time series to spatial variability of the sediment attenuation. While the detailed arrival structure of the acoustic time series was highly sensitive to variability in the bottom sound speed defect case, here we observe that the structure is highly predictable, with the average and the unperturbed arrival time series being highly similar. However, the variability in the bottom attenuation does cause a high degree of variance to the amplitude of the arrival time series, as the bottom panel of Fig. 5 shows.

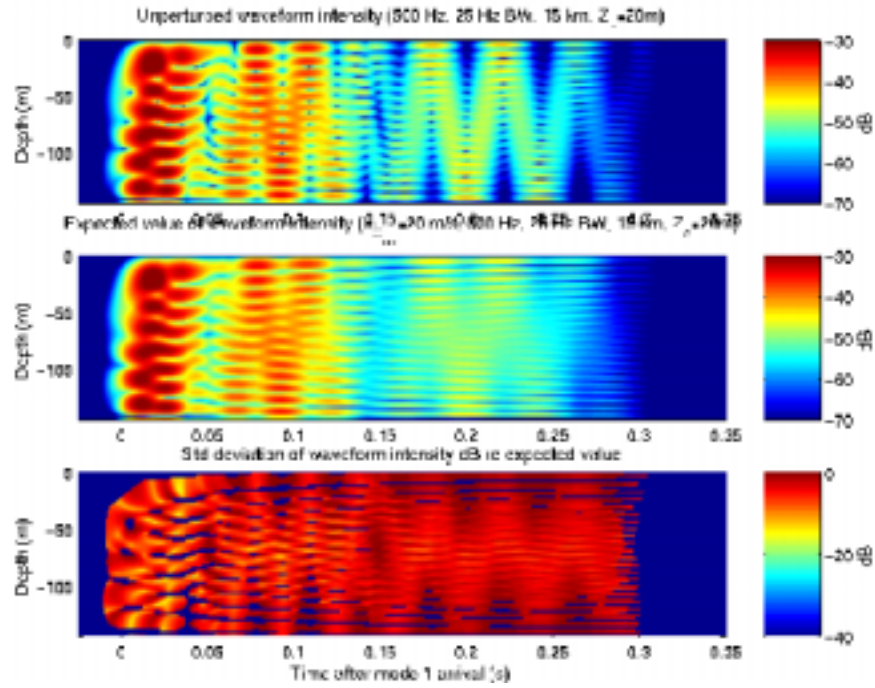


Figure 4. Unperturbed (top), mean (middle) and normalized standard deviation (bottom) of the time-depth evolution of received intensity in a shallow water waveguide in the presence of slow bottom variability. The middle and bottom panels show that the entire arrival structure is highly sensitive to bottom variability, with a correspondingly high standard deviation over the entire time-depth history.

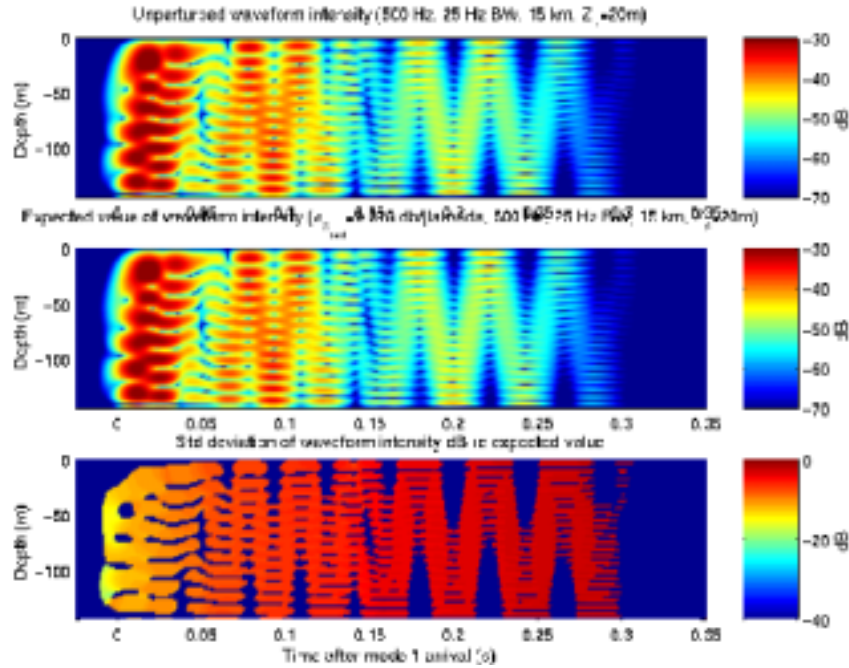


Figure 5. Unperturbed (top), mean (middle) and normalized standard deviation (bottom) of the time-depth evolution of received intensity in a shallow water waveguide in the presence of bottom attenuation variability. The middle and bottom panels show that while the coherent structure of the arrival structure is highly predictable, the levels are not.

From these results we conclude that bottom and oceanographic variability affect the predictability of acoustic time series in shallow water in highly different ways. For oceanographic variability, we find that it is the earliest arrivals that are most strongly affected by internal waves, due to the highly anisotropic nature of the sound speed perturbations correlation length scales in the horizontal and vertical direction. On the other hand, bottom sound speed variability strongly degrades the predictability of the whole time series for slow bottoms, while bottom attenuation variability preserves the predictability of the structure but not the level. Other results not shown here for fast bottoms indicate that it is the later arrivals alone that are most affected by bottom variability, due to the fact that the lower order modes which arrive earlier interact less strongly with the bottom uncertainty.

IMPACT/APPLICATIONS

This work is directed towards identifying how variability in various seafloor geoacoustic properties introduces uncertainty in coherent acoustic transmissions and reverberation in shallow water environments. The analytic tools being developed make it possible to predict the different impact of the different types of variability; for instance the results shown above indicate that seafloor variability affects the entire signal structure in shallow water for slow bottoms, but only the coda for fast bottoms. Internal wave-type oceanographic variability, on the other hand, is seen to mostly affect the leading edge of acoustic transmissions. This type of information will be useful to the extent that coherent processing of underwater signals and reverberation is foreseen in notional system designs.

TRANSITIONS

None

RELATED PROJECTS

Working with other members of the seabed variability team. John Goff, UTIG, and Larry Mayer and Brian Calder, UNH are providing statistical characterizations of the sediment sound speed and bottom bathymetry. These inputs can be used directly in the analytic tools discussed here. Charles Holland, ARL-PSU, is characterizing the spatial variability of the bottom geoacoustics and related scattering strengths. Information about the variability of the scattering strength and scattering mechanisms will be useful as the models discussed here are extended to treat variability in scattering. James Syvitski, INSTARR, and Lincoln Pratson, Duke, are providing realizations of the seafloor geology and geoacoustics. This information is complimentary to the statistical characterizations of Goff, Mayer and Calder. Bob Odom, APL-UW, is evaluating the observability of sediment variability by acoustic waves using Frechet derivatives. This work is directly related to the perturbative analysis undertaken here for evaluating the effects of environmental variability on acoustic modes. Chris Harrison, SACLANTCEN, will introduce the effects of seafloor uncertainty into the SUPREMO system performance model: it is anticipated that we will have close interactions on how to take the teams results relating basic uncertainty in sediment geology and geoacoustics to acoustic propagation and reverberation uncertainty and propagate these results through to the ultimate impact on systems performance.

REFERENCES

- [1] Krolik, J.L., “Matched field minimum variance beamforming in a random ocean channel,” *J. Acoust. Soc. Am.* **92**, 1408-1419 (1992.)
- [2] LePage, K.D., “Time series variability in fluctuating ocean waveguides,” SACLANT Undersea Research Centre SR-319, La Spezia, Italy (1999.)
- [3] LePage, K.D., “Bottom reverberation in shallow water: Coherent properties as a function of bandwidth, waveguide characteristics, and scatterer distributions,” *J. Acoust. Soc. Am.* **106** 3240-3254 (1999.)

PUBLICATIONS

LePage, K.D., “Acoustic time series variability and time reversal mirror defocusing due to cumulative effects of water column variability,” *J. Comp. Acoust.* **9**, 1455-1474 (2001.)

LePage, K.D., “Modeling propagation and reverberation sensitivity to oceanographic and seabed variability,” In *Impact of Littoral Environmental Variability on acoustic Predictions and Sonar Performance*, Pace, N.G. and Jensen, F.B., 353-360 (Kluwer, The Netherlands, 2002.)

LePage, K.D., “Modeling propagation and reverberation sensitivity to oceanographic and seabed variability,” SACLANT Undersea Research Centre SM-398, La Spezia, Italy (2002.)